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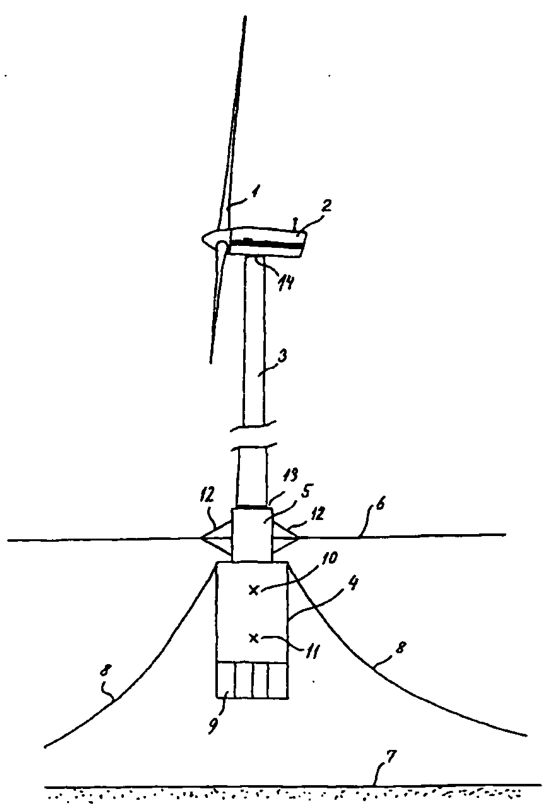
(54) Title: OFFSHORE WIND TURBINE WITH FLOATING FOUNDATION



(57) Abstract: The invention relates to offshore wind turbines supported on a floating foundation comprising a submerged buoyancy body that is secured to the bottom of the sea by one or more wires etc. By proper design of the buoyancy body and associated wires it is possible according to the invention to restrict and/or control the inclination of the tower of the wind turbine and to maintain the position of the wind turbine on site.

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OFFSHORE WIND TURBINE WITH FLOATING FOUNDATION

TECHNICAL FIELD

The present invention relates to wind turbines as set forth in the preamble of claim 1 and more particularly to offshore wind turbines supported on a floating foundation.

BACKGROUND OF THE INVENTION

Wind turbines for converting wind energy to electrical power have been known and applied for many years but have found a dramatically increased application as an alternative energy source during the last couple of decades. It has become common to place wind turbines together in large groups of turbines often counting hundreds of wind turbines within a restricted area. Such large collections of wind turbines can provide an environmentally less desirable solution both from an aesthetic point of view and also due to the inevitable noise problems they cause. Furthermore the positioning of wind turbines on land may not always be an optimal placement, as it is preferable that the blades of the wind turbine be located in a laminate flow of air which is not always obtained due for instance to the presence of hills, woods, buildings etc. It has hence become popular to locate groups of wind turbines offshore, not too far from the cost at locations where water depths allows the wind turbines to be fixedly attached to a foundation provided at the bottom of the see. Over water the flow of air is not disturbed by the presence of various obstacles as mentioned above, and furthermore such placements may be advantageous from an environmental point of view.

Due to the large dimensions of present day wind turbines – dimensions which furthermore tends to increase due to the relation between the diameter of the rotor and the maximum electrical power which the wind turbine can provide – it is vitally important that the wind turbine be provided with a stable foundation. This is not in principle a problem for wind turbines located on the ground but becomes a problem in connection with offshore wind turbines. One prior art solution is to mount the tower of the wind turbine on a suitable construction of pillows and grids, this construction being fixed to a firm foundation on the bottom of the see, but this solution is expensive and primarily applicable at relatively shallow waters, i.e. up to depths of around 25 meters.

In practice it is thus important to be able to limit the inclination angle of the tower of the wind turbine relative to the vertical direction to a certain, predetermined maximum inclination angle.

The target inclination angle of the tower relative to the vertical direction of the wind turbine should always necessarily be substantially 0 degrees. During operation the wind force acting on the wind turbine will partly be transformed into rotational energy of the blades and associated mechanical components and partly into a moment tending to bend the tower of the wind generator in the direction of the wind force, whereby the tower tends to assume an inclined angle relative to vertical. It may under circumstances be beneficial to have the tower assuming an inclined position when the wind turbine is only subjected to small wind forces, whereas it assumes an upright position when it is acted upon by heavier wind forces. In practice inclination angles of up to 10 degrees may be allowed although they are preferably held within 3 degrees.

A special problem by using offshore wind turbines may occur where accumulation of ice around and on the tower – for instance in arctic waters – may result in reduced stability of the wind turbine and even lead to its final destruction.

SUMMARY OF THE INVENTION

According to the introduction it is thus an object of the present invention to provide an offshore wind turbine by means of which it is possible to limit said inclination angle of the tower of the wind turbine relative to the vertical direction to a certain, predetermined maximum inclination angle.

It is a further object of the present invention to provide an offshore wind turbine that can in principle be located at water depths far in excess of the above mentioned 25 meters.

It is a further object of the present invention to provide an offshore wind turbine where the inclination angle of the tower relative to the vertical direction can be deliberately varied within certain limits.

These and other objects are attained with an offshore wind turbine according to the characterising clause of claim 1. A number of different embodiments of the invention are defined in the dependent claims.

According to the present invention there is thus provided an offshore wind turbine comprising a nacelle and a tower with a foundation, characterised in that said foundation is formed as a submerged buoyancy body supporting said tower and provided with means for restricting and/or controlling the inclination angle of the longitudinal axis of said tower relative to the vertical direction.

According to the invention there is furthermore provided for defining the position of the wind turbine to a specific offshore site.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described in more detail with reference to the accompanying drawings, in which

figure 1 is a schematic representation of an offshore wind turbine according to a first embodiment of the present invention;

figure 2 is a schematic representation of an offshore wind turbine according to a second embodiment of the present invention;

figure 3 is a schematic representation of an offshore wind turbine according to a third embodiment of the present invention;

figure 4 is a schematic representation of an offshore wind turbine according to a fourth embodiment of the present invention;

figure 5 is a schematic representation of an offshore wind turbine according to a fifth embodiment of the present invention;

figure 6 is a schematic representation of an offshore wind turbine according to a sixth embodiment of the present invention;

figure 7 is a schematic representation of an offshore wind turbine according to a seventh embodiment of the present invention;

figure 8 is a schematic representation of an offshore wind turbine according to a eight embodiment of the present invention; and

figure 9 is a schematic representation of a group of offshore wind turbines according to anyone of the various embodiments of the present invention as shown in figures 1 through 8.

DETAILED DESCRIPTION OF THE INVENTION

In the following a detailed description of various embodiments of the invention is given. Common to all the shown embodiments is a wind turbine known per se comprising a number of blades 1, a nacelle 2 housing generator, transmission means etc. and a tower 3.

With reference to figures 1 to 3 there is shown a first class of embodiments of the offshore wind turbine with floating foundation according to the present invention. These embodiments all comprises a submerged buoyancy chamber 4 a part of which can be filled with a suitable ballast provided in order to locate the centre of gravity 11 sufficiently below the centre of buoyancy 10 of the submerged part of the system in order to obtain a stable foundation for the wind turbine. The tower 3 of the wind turbine is supported on the buoyancy chamber 4 via a transition section 5 penetrating the surface 6 of the water. Also indicated in the figures is the bottom of the see 7. The wind turbine and foundation can in practice be held on station either by means of a plurality of freely suspended wires 8 connected to appropriate anchor means such as suction anchors (not shown in figures 1 to 3 but shown in figures 4 to 7) or alternatively by means of a single wire connected to a single anchor. In the first of these cases the foundation 4, 5 will not be free to rotate about an axis coincident – or parallel – with the longitudinal axis of the tower 3, and hence the nacelle 2 must be able to undergo rotation about said longitudinal axis either by the provision of a rotatable yaw system between the nacelle 3 and the tower 4 as indicated by 14 in the figures or by the provision of

a routable yaw system between the tower 3 and the transition section 5 as indicated by 13. In the latter case where the foundation is held on station by only one anchor and associated wire the wire is attached to the buoyancy chamber 4 in such a manner that the foundation is free to undergo rotation about said axis, and in this case it is possible to avoid the use of the above mentioned rotatable yaw systems 13, 14.

At the bottom of the buoyancy chamber 4 a suitable ballast substance is located, for instance contained within a number of compartments 9 as shown in figure 1. This ballast serves the purpose of providing counterweight to the wind turbine and to establish a common centre of gravity 11 for the whole unit comprising wind turbine and foundation well below the centre of buoyancy of the submerged part of the unit. By changing the distribution of ballast substance in the compartments 9 it is possible to control the inclination angle of the tower and thus if desired counteract the effect of the wind load on the wind turbine. Alternatively it is for instance possible to adjust the distribution of ballast in such a manner that the wind turbine will incline towards the wind velocity at low wind velocities, whereas it will either be vertical or incline in the direction of the wind velocity at higher wind velocities.

It is also possible to utilise the ballast compartments 9 during installation of the unit at its final offshore site. The unit will typically be towed to this site in an essentially horizontal orientation of the tower. When the site is reached the unit will be connected by wires 8 to an appropriate number of anchors such as suction anchors preinstalled at the bottom of the sea whereafter the ballast compartments 9 can be filled with a suitable ballast substance thereby facilitating the raising of the tower 3 to its final substantially vertical position.

Finally in areas with ice occurrence the transition section 5 may be provided with ice breaking means as indicated by the ice cone 12 shown in figure 1. The movements of the unit resulting from the wind load on the wind turbine increase the effect of the ice cone 12.

With reference to figure 2 the system of ballast compartments 9 shown in figure 1 can alternatively be completely or partly replaced by a movable weight 15 placed for instance on a suitable lever arm 16, so that a movement of this lever arm for instance by hydraulic means 17 will tend to counteract the load of the wind on the wind turbine, thus serving to maintain the tower 3 at a substantially vertical position.

As indicated in figure 3 it is furthermore possible to provide the buoyancy chamber with a system of thrusters 18, of which only one is shown in figure 3. By proper design, placement and control of such a system it is possible to achieve a controlled rotation of the wind turbine about the longitudinal axis L of the tower 3 instead of a freely rotating unit. It is also possible to utilise the system of thrusters 18 to aid in controlling the inclination of the tower relative to the vertical direction.

With reference to figures 4 to 7 there is shown a second class of embodiments of the offshore wind turbine with floating foundation according to the present invention. The main difference between the first class of embodiments as described in connection with figure 1 to 3 and the second class of embodiments to be described in the following is that the freely suspended anchor wires 8 have been replaced by tension anchoring of the buoyancy chamber 4, i.e. the wires 20 (see figure 4) are not freely suspended from the uppermost portion of the buoyancy chamber but kept under tension, whereby they contribute to the controlling of the resultant position of the centre of gravity 11, so that this is located sufficiently lower than the centre of buoyancy 10.

With reference to figure 4 there is shown a complete unit still comprising the wind turbine 1, 2, 3 supported on the suspended buoyancy chamber 4 via a transition section 5. At the bottom of the buoyancy chamber 4 there is attached an anchor connection structure 19, which can be formed as an open grid structure or the like, at the lower end of which a number of wires 20 connects the unit to suction anchors 21 on the bottom of the see. Three such anchors 21 are shown in figure 4, but other numbers of anchors 21 may also be employed.

Figure 4 also indicate the presence of a certain amount of ballast 9' located at the bottom of the buoyancy chamber 4, and it is understood that a system of ballast compartments as indicated by reference number 9 in figure 1 could also be used in the present case if needed.

It is also in the embodiment shown in figure 4 – as in the embodiments shown in figure 5, 6 and 7 - possible to provide the unit with ice breaking means 12, movable ballast means 15 placed on an appropriate lever arm 16 (as in figure 2) and a system of thrusters 18 (as shown in figure 3) if such measures are considered advantageous.

Due to the presence of more than one tension anchoring 20, 21 the unit is not freely routable about the longitudinal axis through the tower 3. It is therefore necessary in the embodiment shown in figure 4 to provide the wind turbine with rotatable yaw systems, either 13 or 14 as previously mentioned.

In order to increase overall stability of the unit and to enable increased tension of the wires 20 it is possible to utilise the alternative embodiment shown in figure 5. The anchor connection structure 19 is according to this embodiment provided with a centrally located, downwardly extending pillar 24 forming a fixed connection between the unit and the bottom 7 of the see. The pillar 24, which can for instance be formed as a tube or a grid construction, can either be preinstalled at the site together with the system of suction anchors 21, but it is also conceivable to form the pillar 24 as a telescopic system, which is mounted at the lower end of the anchor connection structure 19, and which is extended to its proper length on site. It is furthermore both possible to apply a fixed connection between the wires 20 and the anchor connection structure 19, thus preventing free rotation of the wind turbine about the longitudinal axis through the tower 3, but it is also possible to attach the wires 20 and the pillar 24 to a tubular member 23 or the like, which member 24 is rotatably connected to the lower end of the anchor connection structure 19, thereby providing for a free rotation of the wind turbine about the longitudinal axis through the tower 3.

With reference to figure 6 there is shown an embodiment that can be considered an alternative to the one shown in figure 5 and described above. According to the embodiment shown in figure 6 the anchor wires 20 are attached to the uppermost end of the buoyancy chamber 4 in order to increase transversal stability of the unit. In fact it is in principle to attach the wires 20 at even higher levels of the unit, and even to the tower 3. If an attachment to the tower 3 is chosen the rotatable yaw system 14 between the nacelle 2 and the tower must necessarily be provided. As in the previous embodiment shown in figure 5 a pillar 24 is provided, but in the present embodiment extending directly from the bottom of the buoyancy chamber 4 to the bottom of the see 7. Again the pillar 24 could be preinstalled on site or could be incorporated within the buoyancy chamber 4, possibly in the form of a telescopic construction as mentioned above.

With reference to figure 7 there is shown an alternative embodiment still comprising a number of tension anchors, but where the unit is freely routable about the longitudinal axis through the tower 3. According to this embodiment of the invention the tension anchors 21 are connected via wires 20 to a swivel 22 or similar means rotatebly and coaxially mounted at the lower end of the anchor connection structure 19. It would in principle also be possible to connect only one anchor to the swivel, although this is not shown in the figures.

A different embodiment of a buoyancy body as compared with all previously described embodiments is schematically represented in figure 8. It is possible to replace the single buoyancy chamber 4 of the previous figures by a number of separate buoyancy chambers, thereby covering a larger horizontal area and hence further increase the stability of the unit. In figure 8 three such chambers 4', 4" and 4'" are shown, but it is understood that also other numbers of buoyancy chambers could be used. The wind turbine 1, 2, 3 is centrally supported on an exemplary supporting structure 26 and each of the buoyancy chambers 4', 4", 4'" are anchored by means of a wire 8, although it is understood that more than one anchor could be used for each buoyancy chamber. Various systems of ballast compartments, lever arm supported ballast bodies and systems of thrusters can also be incorporated into the embodiment shown in figure 8. It is for instance possible to change the distribution of ballast between different buoyancy chambers through appropriate systems of pipelines or the like connecting the various buoyancy chambers as indicated by reference numeral 27 in figure 8.

With reference to figure 9 there is finally shown a purely schematic representation of a group of offshore wind turbines generally indicated by reference numeral 28, where the specific pattern of wind turbines is established by connecting each suction anchor 21 to at least 1 (and at most 4) buoyancy chamber(s) 4 of a specific wind turbine. Other patterns are of cause also conceivable according to the circumstances.

Although various embodiments of the present invention have been shown and described in the preceding parts of the detailed description it is understood that a person skilled in the art may conceive other embodiments of the invention without departing from the scope of the invention as defined by the following claims. Also it is understood that the term "wire" as used

throughout the description should be understood in its broadest sense, and may also comprise other bendable connections such as chains, robes, hawsers etc.

CLAIMS

1. Offshore wind turbine unit comprising a nacelle and a tower with a foundation, characterised in that said foundation is formed as a submerged buoyancy body supporting said tower and provided with means for restricting and/or controlling the inclination angle of the longitudinal axis of said tower relative to the vertical direction, said means also defining the offshore position of the wind turbine within predetermined limits.

2. Offshore wind turbine according to claim 1, characterised in that said buoyancy body is formed as a buoyancy chamber (4) connected to the bottom (7) of the see by one or more anchor means (8; 20, 21).

3. Offshore wind turbine according to claim 1, characterised in that said buoyancy body comprises a plurality of buoyancy chambers (4', 4", 4"') connected to the bottom (7) of the see by one or more anchor means (8; 20, 21).

4. Offshore wind turbine according to claim 2, characterised in that said anchor means (8) comprises one or more freely suspended wires (8), one end of each of said wires (8) being attached to said buoyancy chamber (4) and the other end of said wires (8) being attached to an anchor (21).

5. Offshore wind turbine according to claim 2, characterised in that said anchor means (8) comprises one or more pretensioned wires (20), one end of each of said wires (8) being attached to said buoyancy chamber (4) and the other end of said wires (8) being attached to an anchor (21).

6. Offshore wind turbine according to claim 5, characterised in that said buoyancy chamber (4) is provided with a substantially vertically extending pillar (24) connecting the buoyancy chamber (4) with the bottom (7) of the see.

7. Offshore wind turbine according to claim 6, characterised in that the length of said pillar (24) is made variable, whereby it is possible to use said pillar (24) to adjust the tension of said wires (20).

8. Offshore wind turbine according to any preceding claim, characterised in that said wires (8, 20) are connected to said buoyancy chamber(s) (4; 4', 4", 4"') by means of a swivel member (22).

9. Offshore wind turbine according to any preceding claim, characterised in that said buoyancy chambers comprises ballast contained within at least one ballast compartment (9).

10. Offshore wind turbine according to any preceding claim, characterised in that at least a portion of said ballast being provided by means of a ballast body (15) attached to said buoyancy chamber (4) by means of a movable lever arm system (16, 17).

11. Offshore wind turbine according to any preceding claim, characterised in that said buoyancy chamber being provided with a system of thrusters (18).

12. Offshore wind turbine according to any preceding claim, characterised in that said buoyancy chamber being provided with ice breaking means (12).

13. Offshore wind turbine according to claim 3, characterised in that said plurality of buoyancy chambers (4', 4", 4"') are interconnected by a supporting structure (26), said structure also supporting said tower (3) of the wind turbine.

14. Offshore wind turbine according to claim 13, characterised in that said plurality of buoyancy chambers (4', 4", 4"') are interconnected by channel members (27) through which ballast may pass from one of said chambers (4', 4", 4"') to one or more of the other chambers (4', 4", 4"').

15: Offshore wind turbine according to any preceding claims, characterised in that said anchors (21) are suction anchors.

16. System of offshore wind turbines according to any preceding claim, characterised in that each of said anchors (21) can be connected to at least one of said wind turbine units, whereby offshore groups (28) of wind turbine units can be formed.

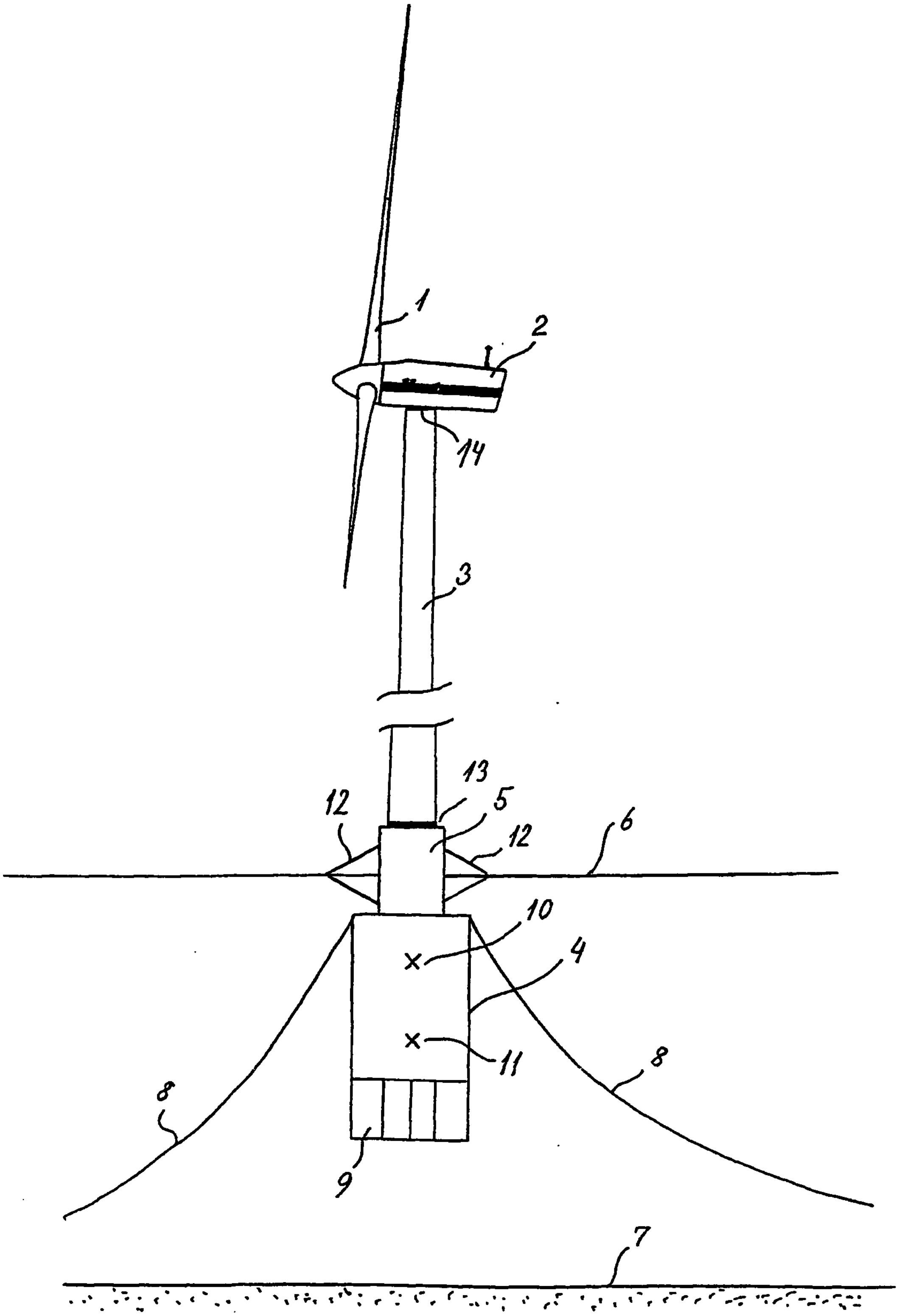

Fig. 1

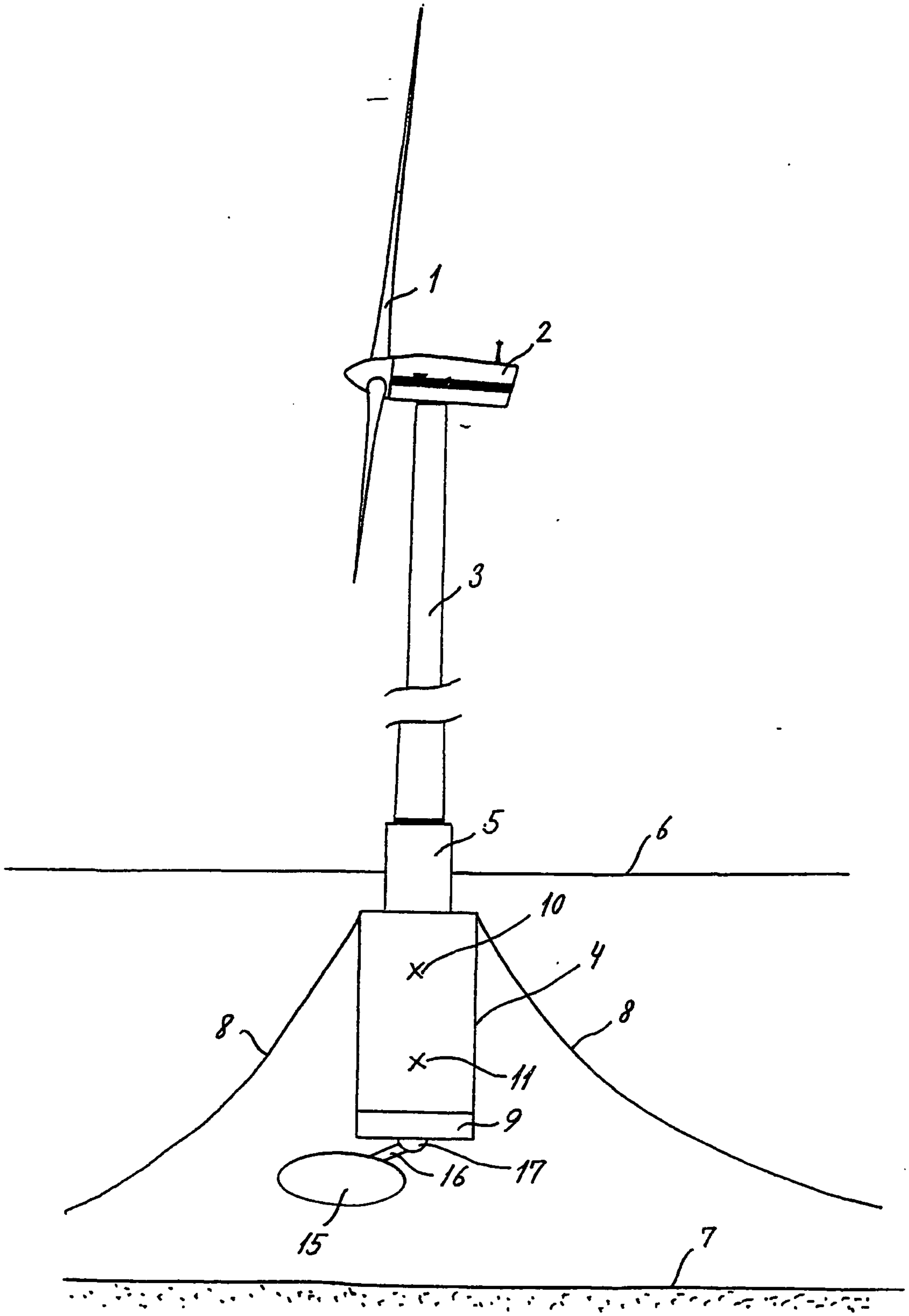

Fig. 2

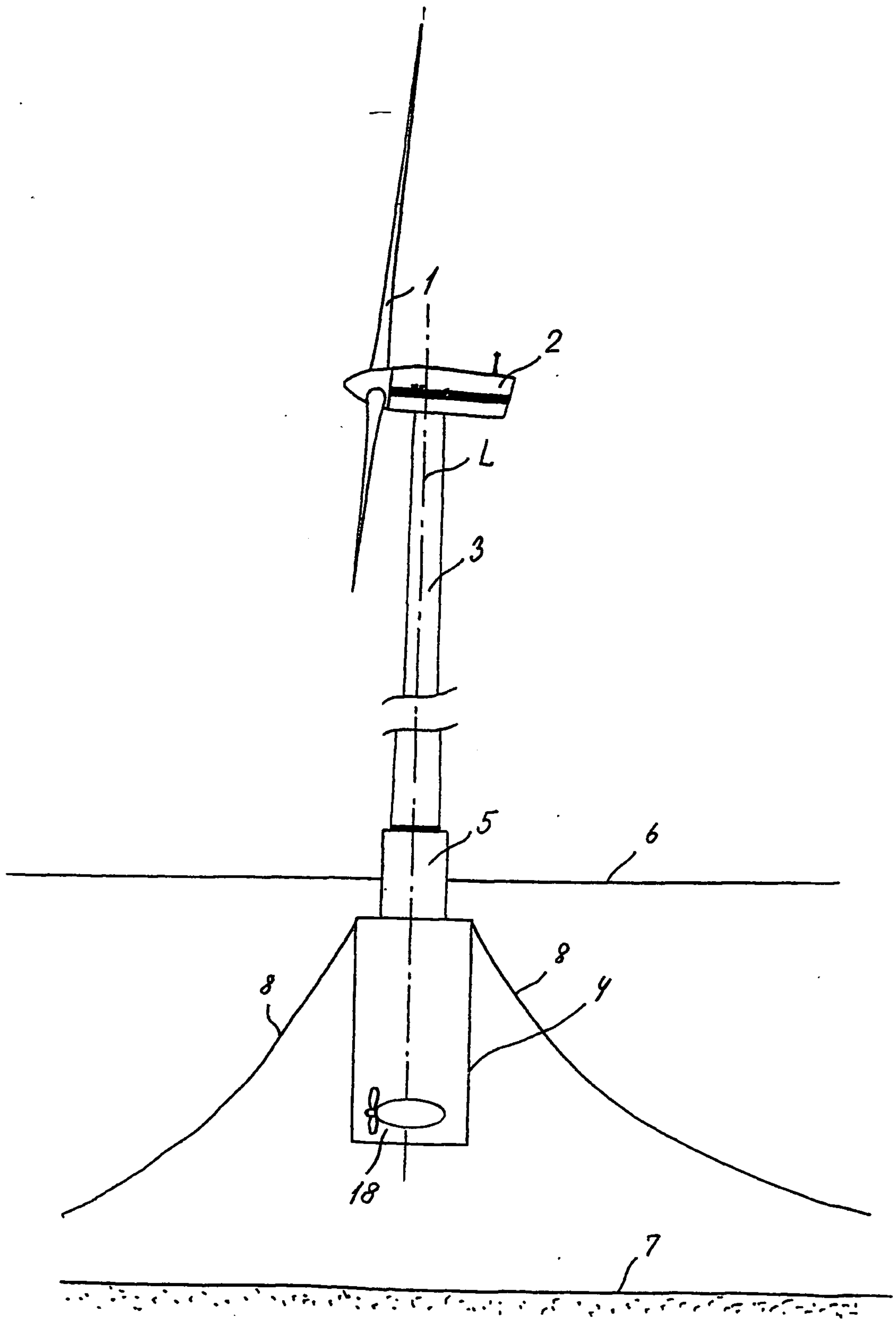

Fig.3

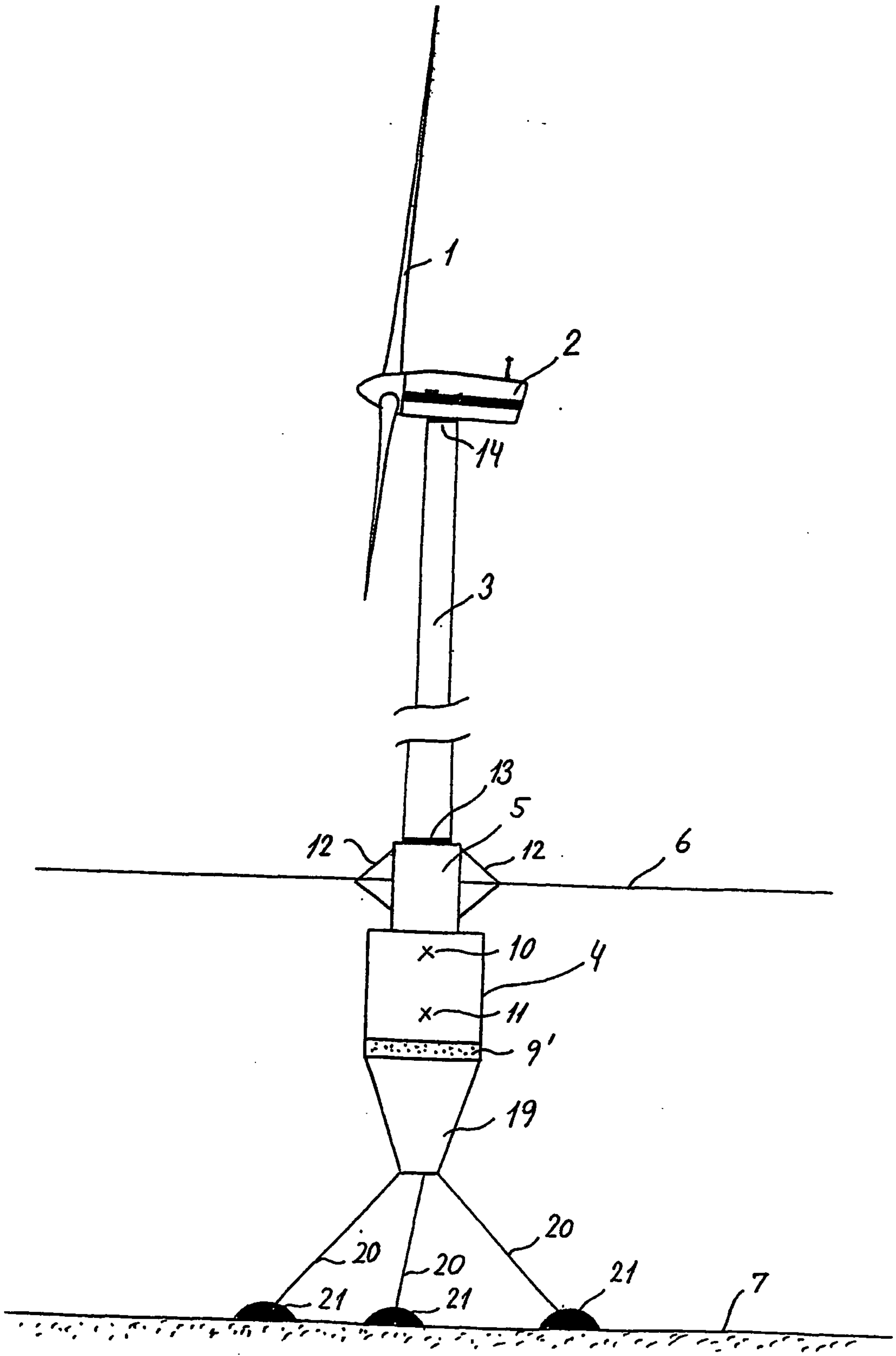

Fig. 4

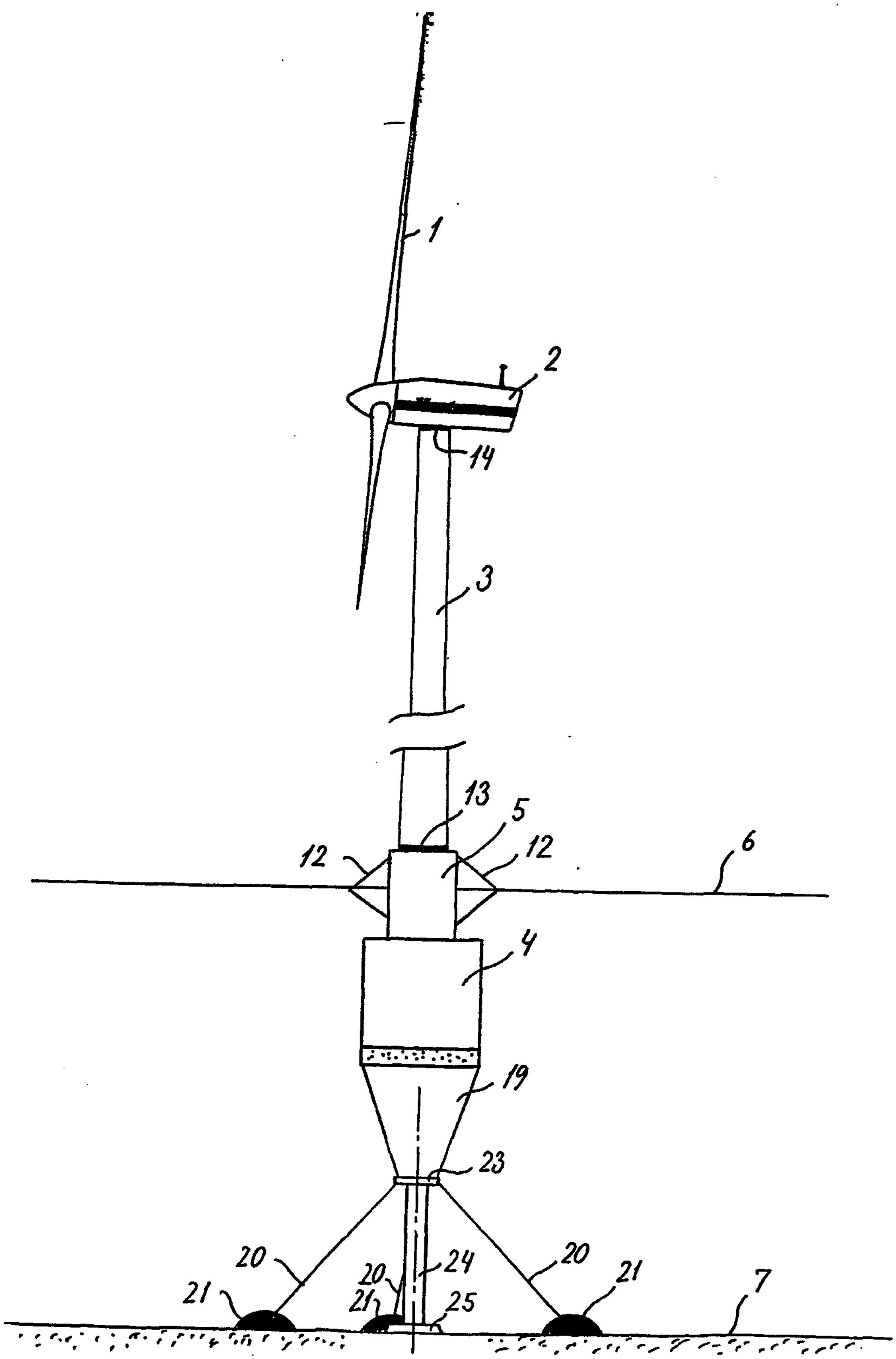

Fig.5

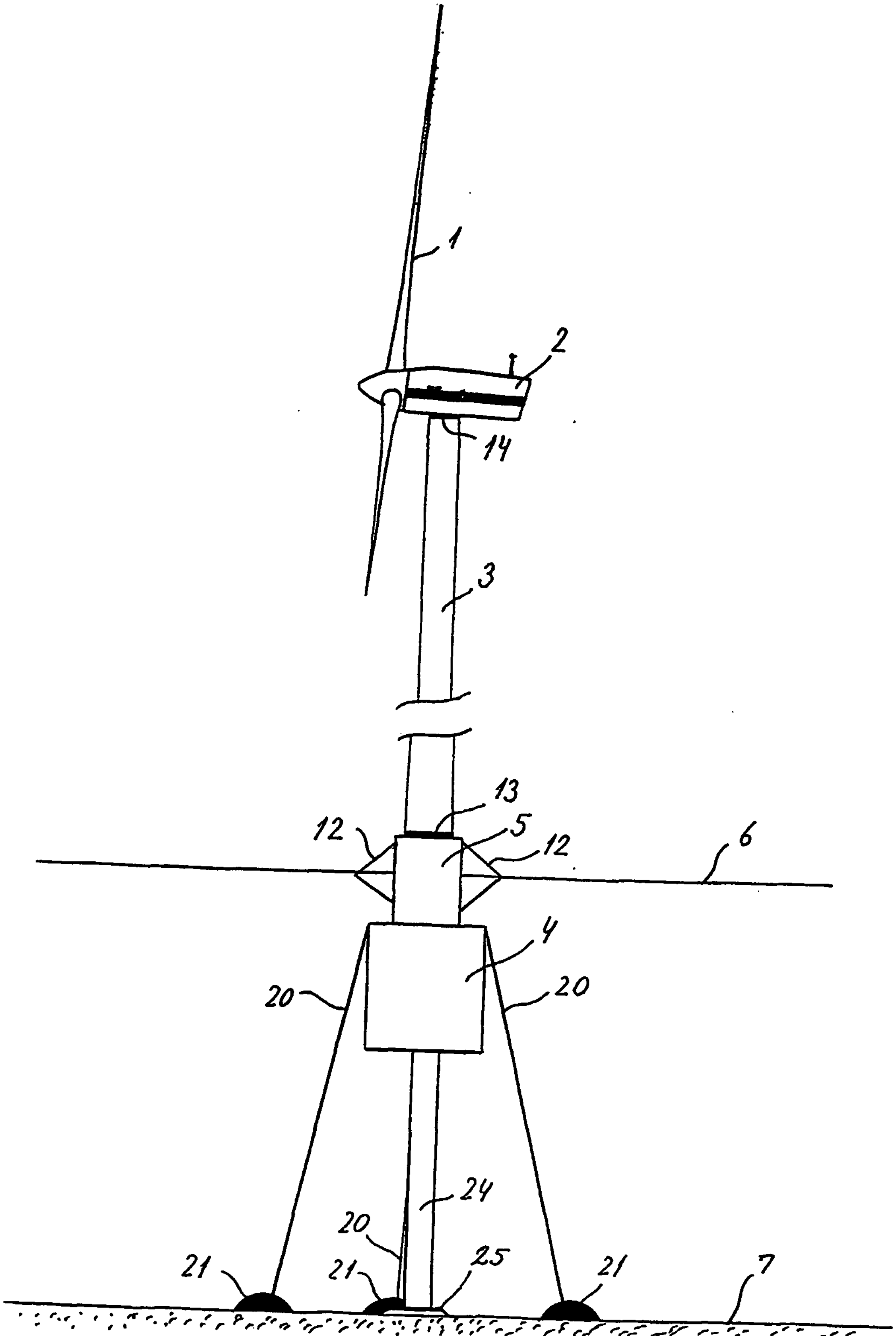

Fig.6

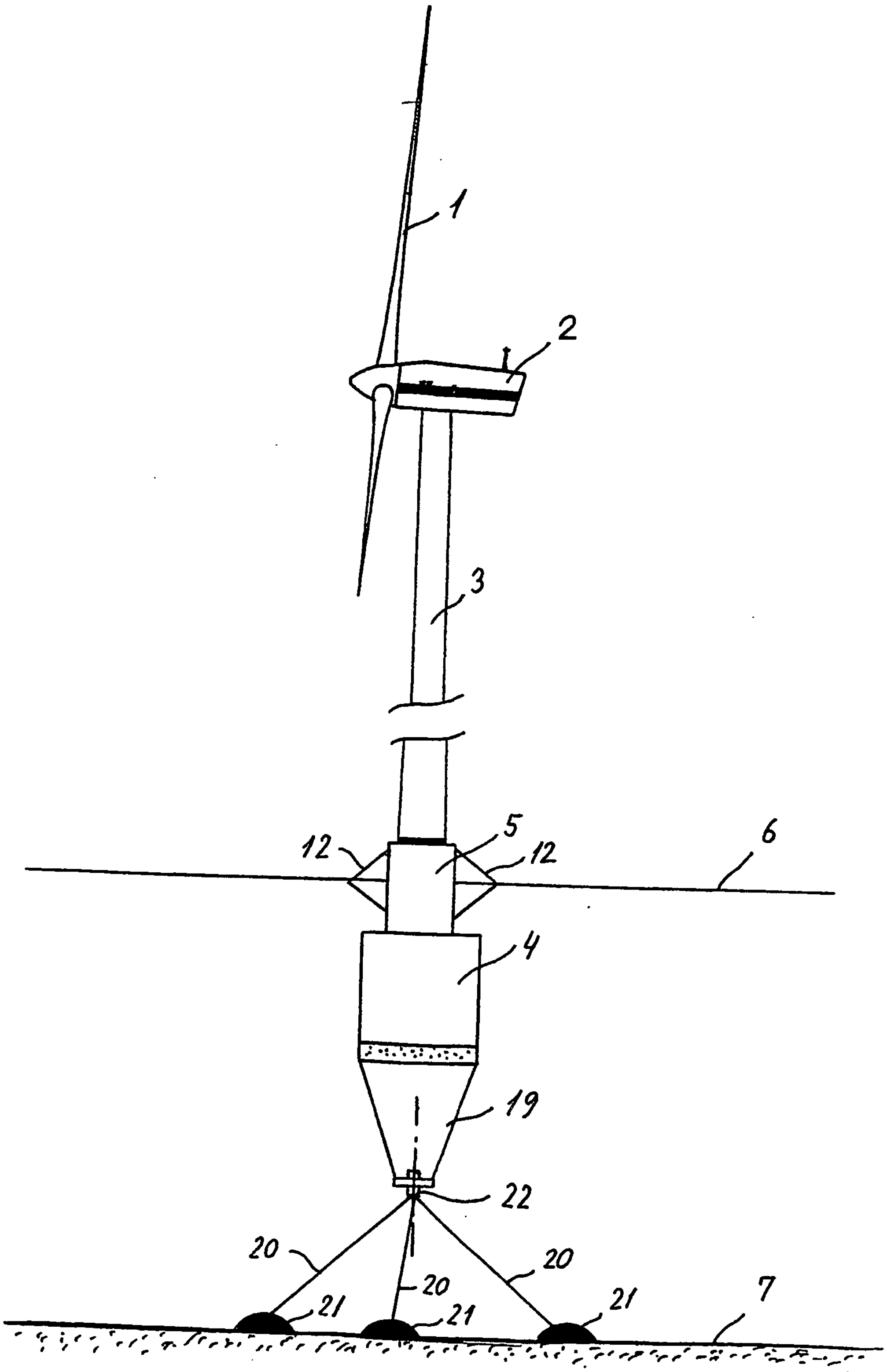

Fig. 7

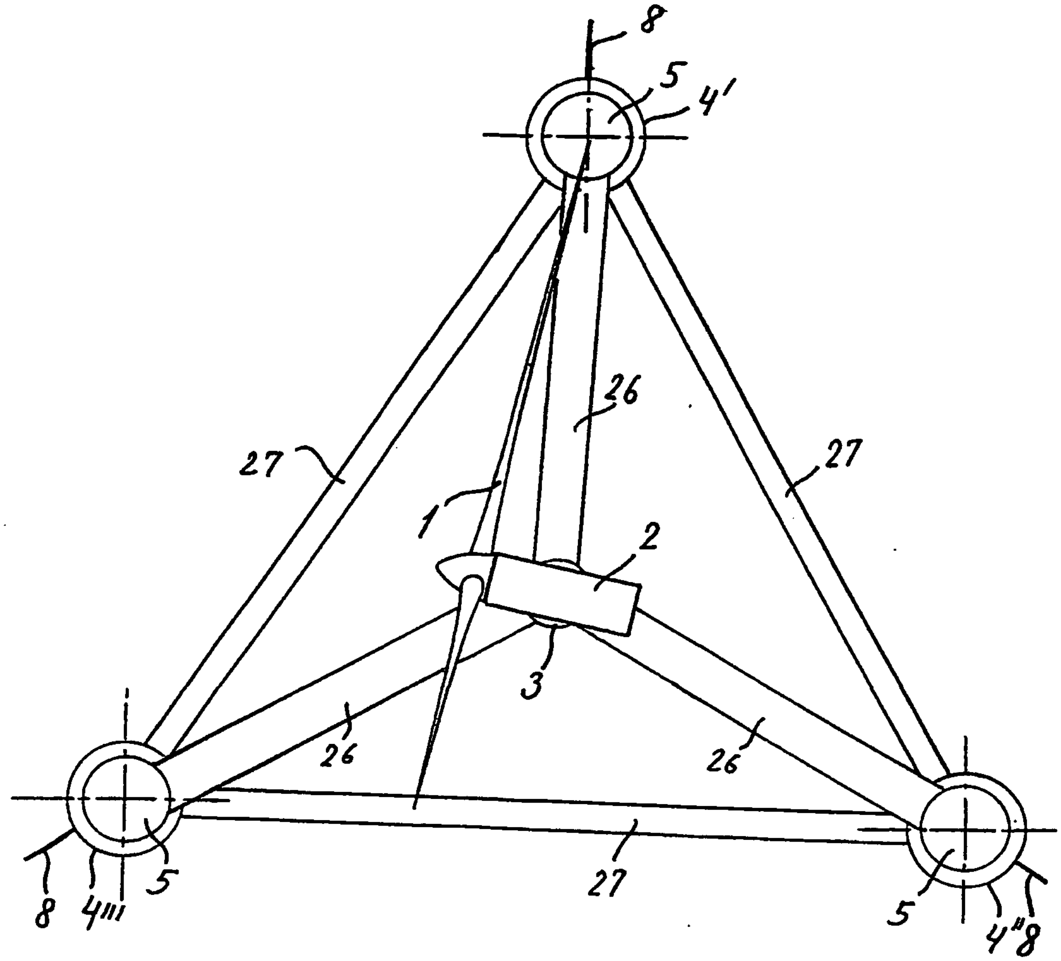

Fig. 8

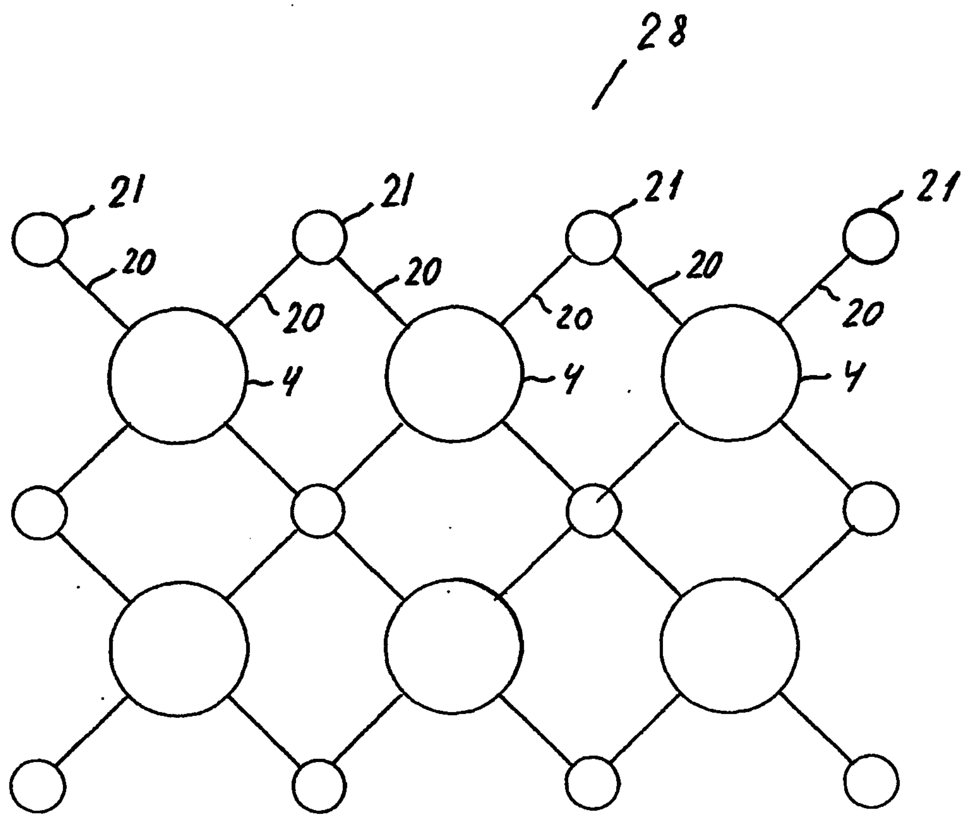

Fig. 9

INTERNATIONAL SEARCH REPORT

International application No.
PCT/DK 01/00473

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: F03D 11/04

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: F03D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-INTERNAL, WPI DATA, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 19744174 A1 (OTTO, GERD-ALBRECHT), 8 April 1999 (08.04.99), column 5, line 62 - line 65, figures 1-7, abstract --	1,2,4-10,15
X	EP 0074938 A2 (SUNDMAN, STIG), 23 March 1983 (23.03.83), page 3, line 32 - line 36, figures 1-3, abstract --	1,2,6,7,9,11
X	DE 3107252 A1 (ERNO RAUMFAHRTTECHNIK GMBH), 9 Sept 1982 (09.09.82), figures 1-4, abstract --	1,2,4,5,8,9, 15

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
22 January 2002	14 -02- 2002

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INTERNATIONAL SEARCH REPORT

International application No.
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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
E,X	WO 0173292 A1 (LAURITSEN, PER), 4 October 2001 (04.10.01), figures 1-5, abstract --	1-5,8,9, 13-15
X	DE 19846796 A1 (KOLBERT, DIETER ET AL), 13 April 2000 (13.04.00), figures 1-10, abstract -- --------	1-5,8,9, 13-15

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/DK 01/00473

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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EP 0074938 A2	23/03/83	SE 0074938 T3	
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		FI 67745 B,C	31/01/85
		FI 812844 A	15/03/83
		JP 58057084 A	05/04/83
DE 3107252 A1	09/09/82	NONE	
WO 0173292 A1	04/10/01	NONE	
DE 19846796 A1	13/04/00	NONE	